Active Learning in University:
An Approach to a Freshman Science Course

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Conference Key Areas: Innovative Teaching and Learning Methods

Keywords: Integrated Science, Active Learning

INTRODUCTION

Student-centred active learning approach in undergraduate science education has increasingly been adopted by a number of universities world-wide during the past few decades, and mounting evidence indicates positive impacts of the active learning approach on students' learning outcomes [1,2]. Some notable active-learning models such as *Student-Centred Active Learning Environment with Upside-down Pedagogies* (SCALE-UP) at North Carolina State University [3] or *Technology-Enabled Active Learning* (TEAL) classes at MIT [4], have successfully been applied especially to large enrolment classes. Moreover, real-life challenges faced by tomorrow's engineers in this ever-changing world demand a strong interdisciplinary foundation applicable to real-life situations. To that end some universities have designed their own integrated science courses such as the *Integrated Quantitative Science* at University of Richmond [5], *Frontiers of Science* at Columbia University [6], and *What is Life* at Harvard University [7].

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As a pioneer university in Turkey in implementing a liberal-arts based educational model, Sabanci University envisions its graduates (~70% engineering majors) to be able to thrive in an interdisciplinary environment and to be able to tackle real-life problems from different angles. We also expect our students to contribute to the development of science and technology on a global level through participatory teamwork, as well as disseminate the gained knowledge to the benefit of the community. The pillar of the unique educational model of our University is the first-year core curriculum, taken by all incoming freshman students (~1000 students per semester) regardless of their background knowledge and their prospective majors, which aims at helping students develop the skills for accomplishing these goals and expectations, starting from the very beginning of their university life.

Conforming to the visions of the University, the core curriculum team have also joined the global initiative to place students' learning at the focus and reconsider the roles of instructors in higher education. In particular, our two-semester introductory science course, "Science of Nature" (NS course; 6 ECTS credits per semester), is now offered in active, collaborative learning format in specially-designed classrooms similar to those used in SCALE-UP and TEAL. The NS course was originally custom-designed and has been offered since the beginning of our relatively-young University. The course aims to initiate curiosity and desire for learning "scientific thinking" in students, and at the same time introduces some of the basic concepts of natural sciences. At the same time, in the NS course we place high priority in skills such as critical thinking, systematic problem-solving strategy, scientific literacy and teamwork, all of which are quite essential and valuable skills for all professionals including engineers. However, over the years the course had lost its interdisciplinary nature and more importantly, all the components of the course were given with traditional pedagogy, which had become outdated and ineffective for the student profiles that changed over these years. The profile change is due to i) the decrease in the ratio of students on full scholarships from ~80% to ~40%, ii) the changes in the secondary education system and in the central university entrance exam mechanism in our country, and iii) the increase in the number of freshmen students from ~200 to ~700 in over 10 years. These factors resulted in the drop in the level of academic performance of students (see *Fig. 1.*), more diverse background of the freshman students and drop in attendance rates. Necessitated by the profile change, as well as to stay up to date in "Scholarship of Teaching and Learning" (SoTL) [8] and to preserve our University's leading position in the education scene of Turkey, we thoroughly reviewed and revised the NS course in 2013.

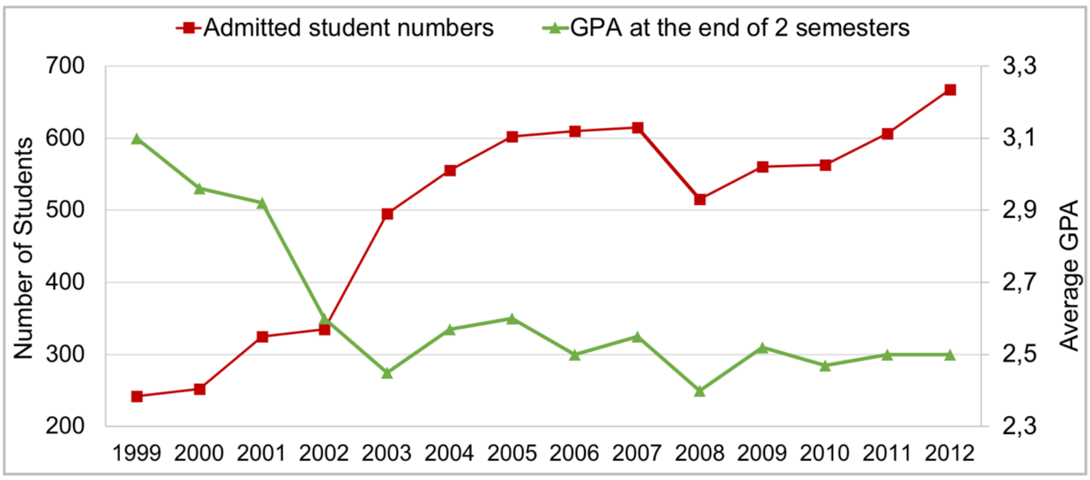


Fig. 1. Average GPA (green, right axis) at the end of the 2nd semester and number of admitted students (red, left axis) since 1999

Throughout the revision and implementation process, the key question we pursued was "How can an introductory science course more effectively help prepare our engineering students to cope with real-life challenges?" In response to that, the methods we chose were active, collaborative learning with student-centred course design, using integrated science contents that are relevant to students' daily life and interests.

1 THE NS REVISION AND COURSE DESIGN

1.1 Pre-Revision Course Format

The NS course consists of NS101 and NS102 taken in sequence. Before the revision, physics topics were taught in NS101, followed by chemistry and biology in NS102, all with rather classical contents. The weekly structure of the original version consisted of two two-hour lectures given in a large auditorium (~350 students) and one two-hour recitation (problem solving session) in a classroom with ~25 students. The lectures were taught in a non-interactive, traditional manner and students were mostly passive listeners throughout the course. The recitations were taught by graduate teaching assistants (TAs) who solve conceptual and numerical problems related to the weekly content, on the board. Additionally, there were three lab sessions per semester, where students performed basic physics, chemistry, or biology experiments as a group and wrote reports. The exams (two midterms and one final) were the major assessment tools used to evaluate students' performances in the course, constituting 50−70% of their course grades, depending on the semester. The rest of their grades were obtained from weekly quizzes taken in the recitations and from the lab reports. These assessments were all summative. By 2012, the attendance rates had dropped significantly; on average, the rates were ~40% in the lectures and ~60−70% in the recitations, and the course failure rate had soared to as high as ~40%.

1.2 The Revision Approach: The Structure and Contents

The revision process was initiated in 2012 by a team of faculty members who had taught the NS course with classical contents in the traditional format. The team first analysed pedagogical approaches, curricula, and designs of similar science courses offered by the leading universities in engineering education (including those listed in Introduction) and determined the framework of the revision: the student-centred "backward course design" model [9], with all learning activities and assessments aligned with students' learning objectives.

In addition, we adopted a modular structure around four major open questions in science, concerning Nature and relevant to our daily life:

1. Are we alone in the Universe?
2. Is antibiotic resistance a big threat for the humankind?
3. Are humans causing climate change?
4. Can we ever comprehend the workings of the brain?

Within each of these four modules, the basic concepts of physics, chemistry and biology and their interconnections are emphasized to bring back the interdisciplinary aspect of the course. We note that while the format of the course is disruptively revised, there is ~70% overlap in topics with what were previously taught. The new courses additionally provide materials that serve to bridge the topics in different disciplines. With this revised model, we aim to strike a balance among development of higher order thinking and learning skills, learning of fundamental facts specific to the three disciplines and personal development for the students.

1.3 Revised Course Format

Each module is 7-week long (2 modules per semester), and all students must take all four modules in sequence. The weekly course structure of the revised NS course begins with a pre-lecture worksheet, aiming to prepare them for the main concepts of the upcoming week. The lectures are still given in the same large auditorium; however, a classroom response system with peer discussions, online simulations, and “muddiest point” feedback are incorporated in the lectures, to change the role of students from passive listeners to active learners. The recitations are now held in specially-designed classrooms with round tables and whiteboards all around to promote collaborative learning, where students work on problem sets in small groups. The recitation sections are led by “Master TAs” (MTAs), who are TAs specifically trained in pedagogy and classroom management in the active-learning environment. The MTAs coordinate a team of fellow TAs and undergraduate learning assistants (LAs), who facilitate collaboration among the student groups, assess the students’ conceptual understanding, and provide timely feedback to the students during recitations. An online quiz closely related to the recitation problems is administered at the end of each recitation session. Finally, students work on an online homework set to reflect on the weekly contents and concepts and self-assess their learning level. Students’ performances are evaluated through all of these weekly components: pre-lecture worksheet (10%, formative assessment), lecture participation by answering questions (5%, formative), recitation quiz (20%, summative assessment), and homework (15%, summative but multiple submissions allowed), in addition to two midterm exams, one for each module (25%, summative). NS101 and NS102 have been given in the new format starting from the Spring and the Fall semesters of 2014, respectively, and about 4000 students have taken the NS courses in the new format.

1.4 Pedagogical Training Programs

Another noteworthy component of this NS course revision is the establishment of two professional development programs for students interested in teaching. The programs are designed to train the NS course assistants (both graduate TAs and undergraduate LAs) to become effective facilitators in the student-centred learning environment, and at the same time inform them on the current advances in SoTL. Through these programs, we have trained and worked with ~150 LAs mostly from Faculty of Engineering and Natural Sciences (FENS) and 55 TAs (all FENS) who subsequently worked as MTAs. These programs benefit not only the freshman students taking the NS course but also the assistants themselves to become better educators, leaders, and learners. Many of the LAs go on to contribute to upper level courses as LAs and are also positively changing the learning culture on campus.

2 OUTCOME OF THE REVISED NS COURSE

To evaluate the effects of the revised NS course, we compared NS101 Fall semester data of two years before (2012, 2013) and two years after the revision (2014, 2015) in various aspects. Every year, more than 50% of freshman students are enrolled with the intention of majoring in engineering (FENS) programs and even higher rate of students (~70%) actually graduate from FENS programs at our University. The NS101 enrolment numbers were 652 (2012), 695 (2013), 724 (2014), and 804 (2015).

After the implementation of the revised contents and the active-learning pedagogical structure, a change that we observed immediately was the persistent increase in attendance rates (by two folds for FENS students), both in lectures and recitations (see *Fig. 2*). The increase was much more prominent in the lectures due mainly to the lecture participation (through clicker questions) now being a solid part of the course grade. In the old NS101, the incentive for lecture attendance was 12 questionnaires randomly given throughout the semester and counted towards the course grade as bonus points. The recitation attendance rate increased to 80% on average with the active-learning format. For the rest of the outcome analysis presented here, we focus only on FENS students.

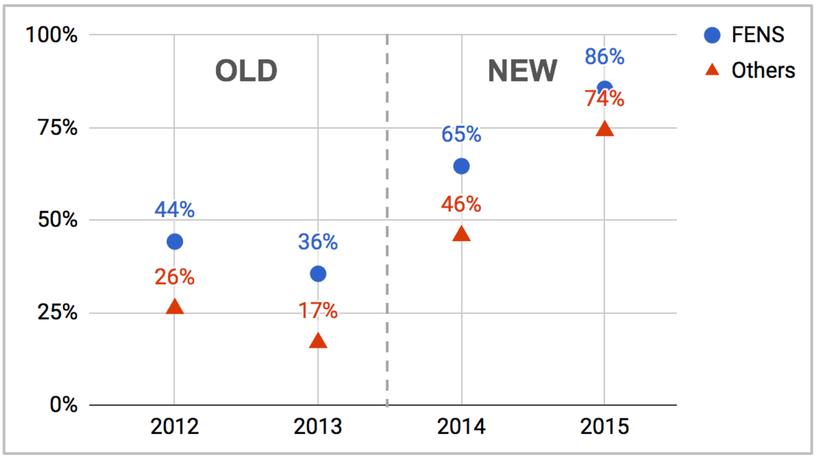


Fig. 2. Rates of students who attended >70% of both lectures and recitations in NS101 Fall semesters sorted by their faculties before (OLD) and after (NEW) the revision

2.1 Skills and Attitudes Surveys

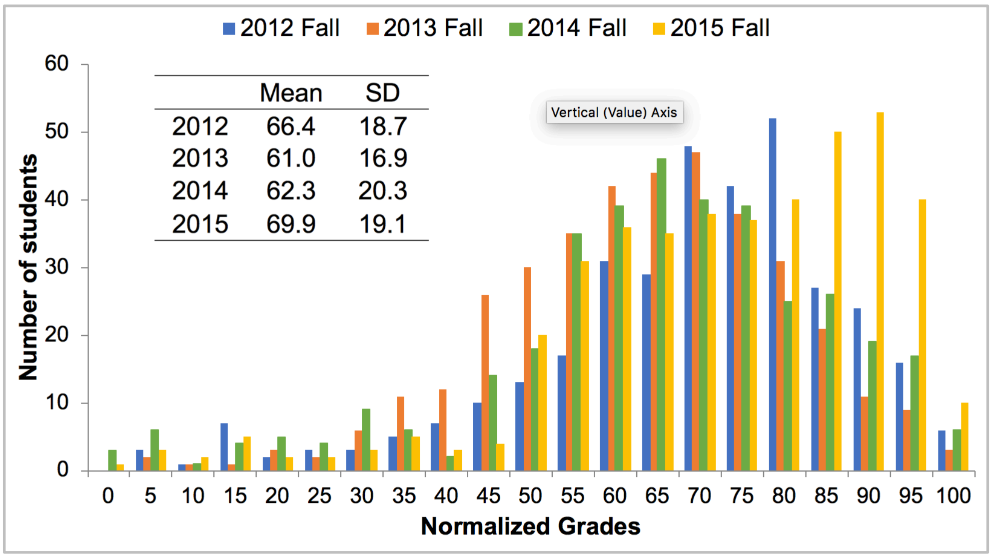
Prior to the implementation, we anticipated some changes in students' perception of their own scientific literacy level as well as general attitudes towards science, with the new NS contents and approach. Therefore, during the semester immediately before the implementation (Fall 2013; F13) and two semesters afterwards (Spring and Fall 2014; S14 and F14), we administered to NS101 students pre- and post-semester surveys to measure students' perception of learning in terms of skills and attitudes, as well as scientific concepts relevant to the NS course. The survey questions were adapted from a validated assessment tool, *Student Assessment of their Learning Gains* (SALG) [10]. The adapted questions were grouped into four categories: A) understanding science, B) skills gained, C) attitude change, and D) learning habit development, encompassing 8, 24, 15, and 18 questions, respectively. We analysed the data obtained from 58 (F13), 62 (S14), and 134 (F14) FENS students who self-claimed in the post-survey that they attended at least half (>50%) of lectures and recitations, and took both pre and post surveys.

To analyse these data, we first quantified the choices in each question (i.e., "a great deal" = 4, "a lot" = 3, "somewhat" = 2, "just a little" = 1, "not at all" = 0), summed each student's responses within each category, and compared the quantified data of pre and post surveys within a given semester (including S14+F14 combined) using paired *t*-test (unpaired data were discarded). We found significant difference ($P < 0.05$) in category A in both F13 and S14+F14, $t(46) = 4.1$, $P < 0.001$ and $t(167) = 3.1$, $P = 0.002$, and in category C in S14, $t(53) = 2.1$, $P = 0.04$. When all the categories are combined, only in F13 a change between pre and post was found at $t(169) = 2.9$, $P = 0.005$.

We also compared the category data between the semesters before and after the course revision using analysis of variance (ANOVA). A significant difference was found only in the category A between F13 and S14 at $F(1,103) = 4.5$, $P = 0.04$. In summary, the results indicated a change in the students' perception of understanding science and a temporary change in their attitude after the revision. On the other hand, their perception on skills and learning habits were not affected by the delivery of the new course. A further, more detailed analysis at question level is needed to understand how these data are different, and such in-depth analysis of the differences is ongoing.

2.2 Grade Distribution Comparison

Due to the different course contents, diversity of student profiles in any given semester and the large enrolment size, which in turn translates to the diversity of the teaching team members, we did not expect to see a significant change in overall grade distributions at least immediately after the revision. Nonetheless, we compared NS101 grade distributions of two semesters before the revision (2012–2013) and two semesters after (2014–2015), in particular the first midterm exam grades, overall course grades and their first-year GPAs. Here, we only compare Fall semesters since the student profiles differ considerably between Fall and Spring semesters. In *Fig. 3*, we show the course grade distributions of the four semesters, for all FENS students registered in each semester. Since the grading scheme of the old and new NS are different, we normalized the course grades to the highest grade of that semester (i.e., the highest = 100) in this comparison. We also present in *Fig. 3* the means and the standard deviation of the distributions. When comparing the combined grade distributions of the old (2012+2013) and new (2014+2015) format using one-way ANOVA, we find $F(1,1503) = 7.79$, $P = 0.005$, indicating a significant difference with a slightly higher mean value.



	Mean	SD
2012	66.4	18.7
2013	61.0	16.9
2014	62.3	20.3
2015	69.9	19.1

Fig. 3. NS101 Fall semester grade distributions of all FENS students over the four years (2012–2015) before and after the course revision. The mean and standard deviation (SD) values of the distributions are also shown as an insert.

In addition, when we compare sub-groups of students with grades >75 in old and new semesters, the difference is even more statistically significant whereas no difference is found in the distributions of those with grade below 75. In fact, the rate of students with course grades >75 increased by from 29% (old) to 38% (new) and continues to remain above 35% every year up to now. On the other hand, despite the increase in the attendance rate, we observe that students with a certain profile who usually would not come to the classes now attend lectures and recitations in the new format, but do not actively participate in the learning activities. Students in general find the integrated contents more challenging, and conceptual questions and interpretation of numerical results weigh more in the assessments in the new format. Therefore, it is crucial in the new system that the students take responsibility in their own learning and actively participate in the discussions in the student-centred learning environment, to further their conceptual understanding of the course topics and eventually to succeed in the course.

2.3 Student Feedback

Among our students, the NS course is generally perceived to be the most challenging and demanding course during the first year, even for future engineering students. In order to assess if this perception changed and to collect general feedback on the modules, we ask students to fill a short questionnaire on how they liked the four modules and why, at the end of NS102 each semester. Their qualitative responses collected since 2015 do not clearly indicate the change in their perception of the challenging/demanding aspect of the course. However, majority of the students expressed their NS course experience as interesting, attractive, interactive, enjoyable, exciting, educative, and beneficial. The students' feedback was mostly focused on interdisciplinary content, their perspective about natural sciences, relation of the course content to real life, and learning environment rather than difficulties of the course. Some example comments taken from the questionnaires are as follows:

- *"All these modules can give students new point of view"* (2017 Fall)
- *"All of the NS course gains me a huge perspective about natural sciences and current problems − especially the ones which involve antibiotic resistance, brain, and climate change"* (2016 Spring)
- *"Interesting and must know subjects for consciousness and get ideas about different disciplines and how connected they can be"* (2016 Spring)
- *"Unlike other schools' science lessons, our modules are very closely connected to the situations in real life (eg: connecting electricity and magnetic fields to the brain and mri scans...) thus it makes it easier and more enjoyable to study on the lesson."* (2015 Spring)

3. CONTINUING REVISION AND PROSPECTS

Although the lectures given in large auditoriums became more interactive, they still remained largely passive compared to other course components. The increase in the attendance rate was a positive outcome but it also brought new challenges for us in terms of sustaining student engagement, student-teacher interaction and managing peer discussions. To address these issues, the NS course went through further revision in its delivery format in 2016, and the course has been offered in a "flipped" format since, in which students work on a preparation set that includes video lectures, readings and quizzes before coming to the class. This allows for more in-class activities and instructor-student interaction time in smaller classrooms (<100 students per section), benefiting both parties. According to the qualitative surveys administered to both students and instructors after the first year of the flipped version, the students' perception of their own learning in this format is mixed while all of the instructors who have taught in this format so far provided positive feedback and deemed the flipped approach largely beneficial for the students.

Here we investigated the impact of the student-centred, interdisciplinary approach on students' learning, attitudes, and perception in our introductory science course given at a large scale. To this aim, we compared the attendance rates and analysed the grade distributions (Fall 2012-Fall 2015), the skills and attitudes survey data (2013-2014), and the student feedback (Spring 2015-Fall 2017). We observed a considerable increase in attendance rates and a statistically-significant difference in the course grade distributions between the traditional and student-centred approaches. To fully understand the nature of the grade difference we found, we are conducting in-depth analyses as well as a comparison analysis of physics concept inventory data collected in 2011 and 2018. Furthermore, the skills and attitudes surveys revealed that students' perception towards "understanding science" is significantly different in the new format compared with the traditional format. Changes in their attitudes were also apparent from the students' end-of-the-course qualitative feedback. The skills and attitudes survey data are being further analysed at the question level to assess the change.

Finally, we note that we have overcome many unique challenges when implementing active-learning pedagogy for such a large class with very broad student background. Transformation from traditional to student-centred learning environment prompts the change of students' role from passive to active learners. This is a rather radical change especially for our students who are, prior to the university, educated to use only the basic level cognitive skills rather than application, analysis, or synthesis skills. Such a change in learning habits develops slowly and a long-term study of the course outcome is needed to show the full impact of the student-centred approach.

We thank Didem Varder-Ulu for consultation and guidance provided throughout the revision process of the NS course.

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